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A COMPARISON OF TRNSYS AND WATSUN FOR THE DEVELOPMENT OF A SDHW MODELING PROGRAM

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ABSTRACT

The development of a standard modeling system is being undertaken by the Solar Rating and Certification Corporation so that different SDHW systems can be compared in a similar way that the Energy Guide is used for comparing conventional hot water systems. Two computer programs, TRNSYS and WATSUN, are examined to assist in performance simulations. Although these programs are used to simulate similar types of SDHW systems, there are significant differences in program structure, time step, material properties, and the modeling of storage tank heat exchangers with stratified storage tanks. Before any useful comparison of the validity of the results from the two programs can be made, it will be necessary to modify the programs so that the same system is being modeled. The incorporation of the most useful components from both of the programs would be a useful addition to the SDHW modeling program.

1. INTRODUCTION

The Solar Rating and Certification Corporation (SRCC) is developing a standardized comparison program which will allow for the evaluation of solar domestic hot-water (SDHW) systems in an analogous way that the Energy Guide is used for conventional hot-water systems (1). The SRCC program will facilitate comparison between solar and conventional hot-water systems. There are presently two primary computer programs which are used for the simulation of SDHW systems: TRNSYS (2) and WATSUN (3). Both of these programs allow the user to determine seasonal performance for several varieties of SDHW systems. The usefulness of these programs lies in their ability to predict such factors as net energy savings, parasitic energy consumption, and thermal losses based upon the particular system configuration and location. The ability of these computer programs to predict overall system performance is especially helpful for use in standardized system evaluations such as that being undertaken by the SRCC for the Sacramento Municipal Utility District. Presently, the SRCC is using a combination of test data and computer simulation via TRNSYS to predict the thermal performance of certified SDHW systems. The performance is reported in the SRCC directory for an average solar/meteorological day for the USA. Additionally, the SRCC will provide annual results for specific locations using Typical Meteorological Year (TMY) data and the models developed for its rating day calculations.

The intent of this study is to compare the TRNSYS and WATSUN modeling of complete SDHW systems, both with respect to what is being modeled by the two programs and how the results for a particular system with a load-side heat exchanger and stratified storage tank compare. This comparison will be helpful in the determination of those features from both of the computer programs or any new considerations which can be incorporated into the SRCC evaluation program to increase the realism and computational efficiency of the SRCC evaluation program. At the present, the SRCC program has been developed using the TRANSED editor which runs a modified TRNSYS program (4).

2. PROGRAM MODELING DIFFERENCES

This investigation is primarily being made to compare what is being modeled by the two programs, rather than comparing the actual correlations being used by the two programs. The three WATSUN models which are relevant to this investigation are the DHWA, DHWS, and SUNS models which are indicated in Fig. 1. These three models are pre-configured models of different hot-water systems. TRNSYS has one partial SDHW module (TYPE 23) which

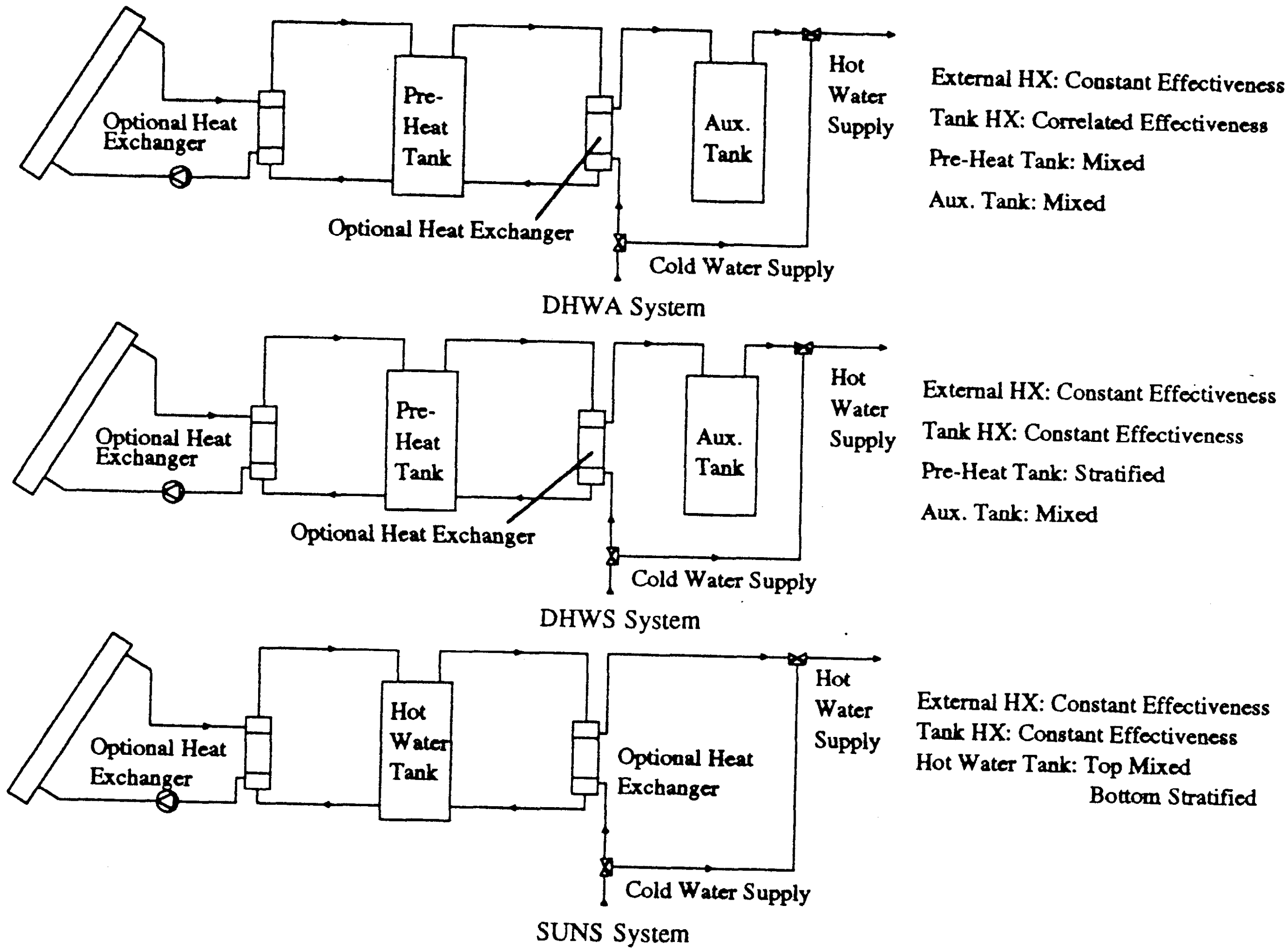

Fig. 1 WATSUN SDHW Models

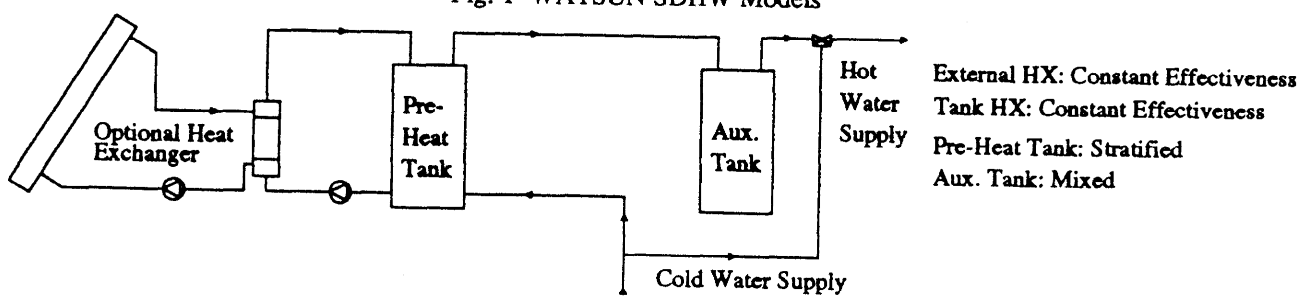

Fig. 2 SRCC TRNSYS SDHW Model

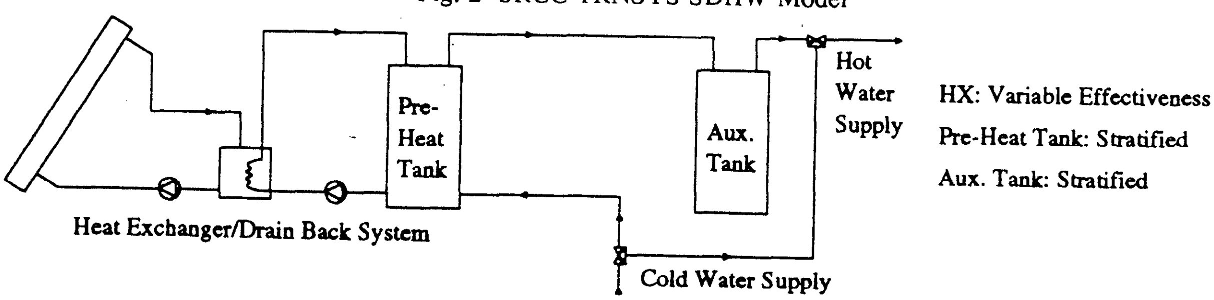

Fig. 3. Actual SDHW Model

was not included in the comparison because it lacks many features needed for the complete system as required by SRCC. All other TRNSYS models need to be constructed from the different subroutines to create a hot-water system. Figure 2 indicates the model which has been set up using the TRANSED editor. This editor allows interactive operation of the TRNSYS program, although the actual program operation proceeds as a batch process and is unaffected by the editor's presence. Figure 3 indicates the actual system which is being modeled. Note that this actual system is not truly modeled by either the DHWS or modified TRNSYS system, although these are the nearest matches from the two respective programs.

Table 1 summarizes the major differences between the standard version of TRNSYS, the modified version of TRNSYS used for the present SRCC evaluation, and WATSUN. This comparison entails the program, the simulation parameters, radiation processing, solar collector, piping and water flow, controller, tanks, heat exchanger, and pumps.

The two primary differences between TRNSYS and WATSUN are the program structure and the time step interval. TRNSYS has a modular structure with a variable time step, while WATSUN consists of several complete, composite systems, using a fixed one-hour time step. Since both programs are written in FORTRAN, either can be modified by the user to accommodate specific simulation needs; however, the concept of a standard SDHW modeling program emphasizes the need to make uniform modifications that will work for all users.

The information summarized in Table 1 reveals some of the limitations and trade-offs of the two programs. The two programs' structures have a large impact on the input process and flexibility. WATSUN allows quick, interactive input for a limited range of systems, while TRNSYS requires significant set-up effort for an unlimited number of configurations. The program structure also has an important effect on the computational efficiency; the advantage of composite system like those used in WATSUN is that they require less subroutine "overhead," can make use of compound equations, and allow rapid input. TRNSYS, while offering unlimited flexibility, makes repeated operational mode checks, cannot take advantage of compound equations, since each unit is modeled separately and requires extensive setup time to create a model.

Another significant difference is the time interval used. This time interval has a major impact on program execution time and on the control interactions of the system. Although the time interval explains some of the computational time differences between the programs; other factors, including the program structure and the mathematical correlations, also have a significant impact on the computational time.

The last major difference lies in the modeling of the heat exchanger used in the collector loop of the hot-water system. As currently configured, neither program offers a true model of certain heat exchanger arrangements (wrap around and immersed coil) in a stratified storage tank. TRNSYS has the capability to model external heat exchangers and a pseudo-constant effectiveness heat exchanger which is used by the SRCC model. WATSUN has the capability to model storage-tank heat exchangers (based upon the natural convective heat-transfer coefficients) for a fully mixed tank, but only the constant effectiveness model can be used with stratified storage tanks. WATSUN also uses the constant-effectiveness value for external heat exchangers.

The development of a more effective storage-tank heat exchanger modeling routine could be performed for either TRNSYS or WATSUN so that a correlation could be used with a stratified tank. Two approaches could be taken. The first approach would be relatively simple to accomplish, and have relatively fast computational speed, but would sacrifice a certain degree of accuracy. This method would use an average temperature calculated for the stratified tank as a basis for determining the natural convective heat-transfer coefficients based upon correlations of the type used in the present WATSUN code. The second approach would sacrifice speed and simplicity for greater accuracy. This method would calculate the heat-transfer coefficient for each of the nodes of the tank in which the heat exchanger is located. Because the solution of the tank model is an iterative differential equation, this solution method would require a "second level" of iteration since each nodal solution would have a different energy input.

3. COMPARISON FOR A TYPICAL SYSTEM

Although the comparison of the results for a typical system using the two programs cannot be expected to compare on a one-to-one basis, an evaluation of the respective results can assist in evaluating the capabilities and the trends of the results of the two programs. Two primary factors were considered in the comparison of the two programs: the heat-exchanger effectiveness (using the constant-effectiveness model) and the number of nodes of stratification in the pre-heat storage tank. The modified TRNSYS system using TRANSED and the DHWS WATSUN model were compared. The various parameters were matched as closely as was possible without modifying either program, although there are a few differences as noted in Table 1. Two important factors were not fully considered: the usability of the delivered energy (water temperature too low) and the true heat-exchanger configuration.

Using the system indicated in Fig. 3, for a residential-sized application, the energy savings as a function of heat-exchanger effectiveness and number of stratified-tank nodes was determined. The following equation is used for calculating the SRCC standard energy savings:

TABLE 1. COMPARISON OF SDHW MODELING BETWEEN TRNSYS AND WATSUN

System parameters	TRNSYS version 13.1	SRCC TRNSYS with TRANSED editor	WATSUN version 12.1
Program structure	Modular	Preset, modular	Preset
Execution mode	Batch	Interactive, batch	Interactive
Dimension units	Any consistent set	IP input, SI/IP output	SI
Simulation time step	As desired	5 Minutes	1 Hr. (some exceptions)
386/20 PC Execution time	Dependent on time step	6 Hours	2-3 Minutes
Weather data	TMY	TMY	TMY
Load used	As desired	Constant volume	Constant energy or volume
Horizontal radiation models	Liu & Jordan, Boes et al., Erbs, Reindl, Direct values	Direct values	Hollands & Brunger Hollands & Chra
Tilted surface radiation	Isotropic sky, Hays & Davies, Reindl, Perez et al.	Isotropic Sky	Temps & Coulson, Kluchner
Collector tracking	Optional	Fixed	Optional
Collector model	Hottel-Whillier, data	Hottel-Whillier	Harrison, CSU
Collector thermal capacitance	No	No	No
Collector water Cp	Fixed value	Fixed value	Function of temp. (table)
Scaled flow rate from test	Yes	Yes	Yes
Second order model	No	Yes	Yes
Biaxial incidence angle mod.	Yes	No	Yes
Second order IAM	Optional	Yes	Yes (table)
Minimum temperature	Possible	No	Yes
Pipe model	Plug-flow	Plug-flow	Duffie & Beckman
Pipe thermal capacitance	Yes	Yes	Yes
Ambient temp. (for losses)	As desired	As desired	As desired
Water mains temperature	Optional	Specified profile	Sinusoidal function
Flow basis	Mass	Volume	Mass, Volume
Cold water tempering	Optional	Yes	Yes
Min. usable hot water temp.	Optional	No, But warning is generated	Yes - load is reduced
Max. hot water temp.	Optional	Yes - Tempering used	Yes - Tempering used
Const. energy / variable flow	Optional	No	Optional
Controller power usage	Optional	Yes	No
Controller sensor locations	As desired	Collector & tank outlet	Collector inlet & outlet
Up.& low. temp.deadband	Yes	Yes	Yes
Fully mixed tank model	Yes	Yes (auxiliary tank)	Yes
Multiple node stratified tank	Yes	Yes (pre-heat tank)	No
Plug flow stratified tank	Yes	No	Yes (depending on mode)
Variable inlet, stratified tank	Yes	Yes	Yes
Fixed inlet, stratified tank	Yes	No	No
Plume entrainment tank	No	No	Yes
Fluid density	Fixed value	Fixed value	Function of temp. (table)
Maximum nodes of stratif.	15	10	21 (all not necessarily used)
Stratified node sizes	Variable or fixed	Fixed	Variable
Ambient temp. (for losses)	As desired	As desired	Set value or Tout
External HX, constant ε	Yes - NTU	Yes - NTU	Yes - General equations
External HX, counter flow	Yes - NTU	No	No
External HX, parallel flow	Yes - NTU	No	No
External HX, tank-in-tank	No	No	Correlation, mixed tank only
Wrap-around HX	No	No	Correlation, mixed tank only
Immersed coil HX	No	No	Correlation, mixed tank only
Side arm HX	No	No	Yes - Table input
Pump	Yes	Yes	Yes (only one)
Fluid heating from pump	No	Yes	Yes

Energy Savings = Delivered Energy - Auxiliary Energy + Total Losses - Parasitic Energy.

Figure 4 indicates the results for the TRNSYS simulation. In most respects the results are intuitive: higher effectiveness and greater stratification yield greater energy savings, with the largest increases for lower effectiveness ranges. This particular data was generated using a 10° C upper controller dead band and a 2.78° C lower temperature dead band.

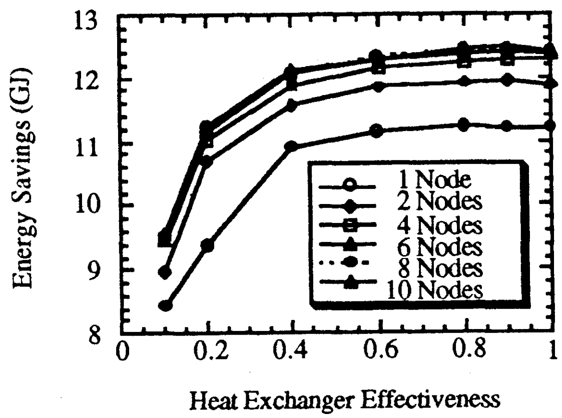

Fig. 4 TRNSYS Energy Savings as a Function of Thermal Stratification and Heat Exchanger Effectiveness

Figure 5 illustrates the analogous results for the WATSUN data. Three primary differences exist between the two data sets. The first difference is that the WATSUN values were not affected by the degree of nodal stratification for the system examined. Both the node-insertion temperature band and the number of nodes was varied, in both cases the system performance appeared to be unaffected. Further analysis of the stratification data shows that WATSUN never used more than four nodes of the allowable maximum number. Because WATSUN uses a plug-flow stratified-storage model, the number of nodes is affected by the time step as well as the tank volume and net flow (5). It should be noted that, for this comparison, TRNSYS and WATSUN use a different method for the determination of thermal stratification, so one-to-one comparisons may be misleading. A previous study of these two programs by Duff and Chandrashekar (6) indicates a noticeable difference between the fully mixed tank and the stratified model, but they did not examine the effect the number of nodes has upon system performance.

The second difference is the influence that the controller-temperature dead bands have on the system performance. Although this effect has been observed in the TRNSYS simulations, its effect appears to be much greater in the WATSUN simulation as indicated in the high-heat-exchanger effectiveness range. It appears that this strong dependence on the temperature dead-band may be a result of the long time-step used by WATSUN. In cases of high effectiveness, and restrictive dead-bands, the system may not gain simulated energy during many hours when there is adequate insolation, although the criteria may be satisfied during a significant part of the hour. The third important difference noted was the difference in the actual values generated for any given condition. However, because there are some differences between the modeled systems, and because the values are of the same magnitude, no meaningful conclusions can be drawn from this difference.

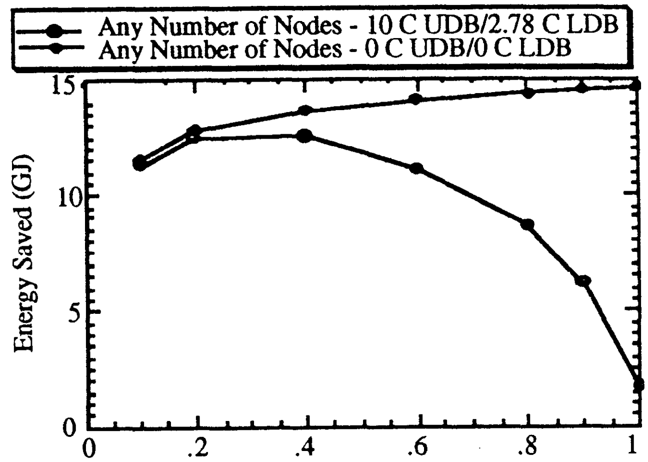

Fig. 5 WATSUN Energy Savings as a Function of Temperature Dead bands and Heat Exchanger Effectiveness

4. CONCLUSION

This comparison of TRNSYS and WATSUN shows that program structure and the time-step has a significant impact on the flexibility, computational time, and validity of results for a SDHW model. Since all three of these factors are important in the development of a SDHW modeling program, the relative attributes of both programs in addressing these issues is important. Neither program currently models the true heat exchanger-stratified tank relationship. The present SRCC TRNSYS model does not incorporate low-temperature flow adjustment that is present in the actual system.

Both of these programs have useful features that can be incorporated into a standardized rating system. Based upon the previous observations, the following changes could be made: Incorporate the storage-tank heat exchangers (using a stratified tank) into either program using the simplified average tank-temperature method. If elements of WATSUN are used, the WATSUN time step will need to be shortened so that the controller effects do not have undue influence on the results,and so that a greater number of nodes will be incorporated into the stratified tank model. If TRNSYS is used, a minimum desired hot water temperature and variable flow rate (so that constant energy is maintained) will need to be added so that low temperature hot water use is evaluated realistically. The TRNSYS execution time could be reduced by combining some of the separate subroutines and creating a specific SRCC model. The incorporation of these changes could greatly aid the development of a more efficient and accurate modeling of solar hot water systems.

5. ACKNOWLEDGMENTS

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